Mobility Support for Vehicular Cloud Radio-Access-Networks with Edge Computing

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***Abstract*—Vehicular networks provide a variety of data services to vehicles through roadside units (RSUs), and cooperation among multiple RSUs is important to support high mobility of vehicles. However, in conventional vehicular network architectures with independently operating RSUs, coordination of RSUs and mobility support for vehicles are limited as the number of RSUs or vehicles increases. We propose using a vehicular cloud radio access network (vCRAN) with edge computing infrastructure where communication and networking resources are centrally controlled. The proposed vehicular network consists of remote radio heads (RRHs) located at roadsides, mobile edge computing (MEC) servers responsible for signal processing and service management, a cloud server managing MEC servers, and a software-defined network (SDN). This vehicular network provides a mobility support method for seamless inter-RRH and inter-MEC-server connections for vehicular services.**

***Index Terms*—Vehicular cloud radio access network, mobility support, SDN/NFV, migration, cooperative transmission.**

I. Introduction

Demand has increased for various vehicular network services and applications. Typically, a vehicular network consists of a number of roadside units (RSUs), which are equipped with radio frequency (RF) modules for wireless connectivity with vehicles. The RSUs process RF signals from vehicles through baseband units (BBUs), and perform wireless medium access control (MAC) operations. All service-requesting vehicles in a network must be associated with RSUs. When a vehicle moves outside the connectivity range of the RSU that is currently supporting it, the vehicle is newly associated with another RSU. Because connections between RSUs and vehicles change dynamically, and significantly affect the quality of service (QoS) of data services, intelligent resource management for mobility support is essential. To this end, a variety of information must be shared rapidly among RSUs. However, it is difficult to share information among RSUs without increases in complexity and overhead, because RSUs operate independently and serve vehicles in a distributed manner.

One approach for establishing a vehicular network that can efficiently manage resources for mobility support is the use of cloud radio access network (CRAN) architecture. A CRAN (CRAN) consists of virtual machines (VMs) in a data center and a number of remote radio heads (RRHs) located on roadsides. RRHs are equipped with RF modules and have minor RSU operation functions. Instead, a cloud server may construct a pool of VMs, with each VM creating a virtual base station (VBS) instance. Such instances perform baseband processing and manage RRHs. Because most communication and network functionalities are centrally performed by the virtualized infrastructure in cloud data centers, optimized resource management can be easily and efficiently achieved [1]. However, although CRAN architecture provides efficient and flexible resource management, long propagation delay between RRHs and the cloud server may cause considerable performance degradation for vehicles with high mobility. Li *et al.* have proposed the mobile edge computing (MEC)-based vehicular CRAN architecture [2]. For vehicular networks, latency is one of the important issues because of high mobility of vehicles. The authors have proposed to deploy MEC server at the network edge, which is connected with RSUs to reduce latency in a vehicular network.

In this paper, we propose a software-defined networking (SDN) and network function virtualization (NFV)-based mobility support method for vehicular CRAN (vCRAN) with MEC. SDN is an emerging network architecture that decouples network control planes from the packet forwarding planes [3]. In an SDN-based network, data forwarding at SDN-enabled switches is fully managed by SDN controllers. As a result, it is easy to perform dynamic data traffic routing for vehicles with high mobility in vCRAN, and to utilize advanced traffic-engineering techniques to achieve QoS improvements. NFV is a network architecture that virtualized network functions (VNFs) consisting of VMs are chained together to provide services flexibly [4]. Using the SDN/NFV-based data flow management, the proposed method provides two mobility support mechanisms; inter-RRH and inter-MEC-server mobility supports. Inter-RRH mobility support provides robust wireless connectivity services to vehicles moving across the RRHs, and inter-MEC-server mobility support renders the MEC servers seamlessly support vehicles when they have to be newly handled in different MEC servers.

II. SDN/NFV-based vCRAN with Edge Computing Infrastructure

In a conventional vehicular network using RSUs, as service requests from vehicles increase and the topology of a network changes dynamically because of vehicle mobility, considerable increases occur in the complexity of establishing and maintain-

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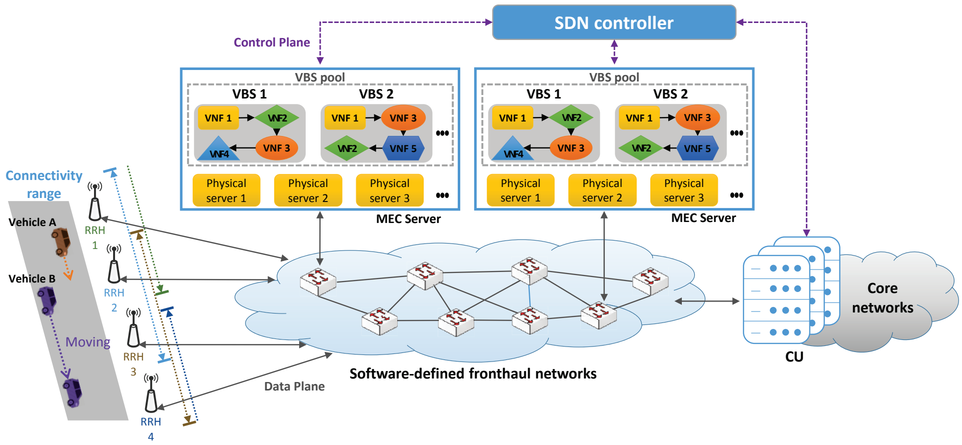


Fig. 1. SDN/NFV-based vCRAN architecture with edge computing infrastructure.

ing connections between RSUs and vehicles. Hence, a new vehicular network architecture that can support both of the flexible resource management and mobility is necessary for improving QoS.

Instead of using a conventional RSU-based vehicular network, we propose using an SDN/NFV-based vCRAN with edge computing that consists of 1) central unit (CU) in a cloud-computing infrastructure, 2) multiple virtual base stations (VBSs) in MEC servers located at the edges of the fronthaul network, 3) an SDN-based fronthaul network, and 4) roadside RRHs, as shown in Fig. 1.

CU and MEC servers: A CU at a cloud computing infrastructure coordinates multiple MEC servers and supports information sharing among MEC servers. In a MEC server located near the edge of the network, multiple VBSs that are responsible for vehicular service are created. To support vehicle mobility, VBSs in each server select a set of RRHs to be connected with vehicles along driving routes. When a vehicle moves outside the connectivity range of the currently connected RRH, then it must be connected to a different RRH. VBSs in a MEC server have high computational power and run an algorithm to select the appropriate RRHs to connect moving vehicles, considering the routes of moving vehicles and various RRH operation conditions.

SDN-based network: In the proposed vCRAN, we deploy an SDN-based network that consists of SDN-enabled switches and a controller. The programmability of SDN-based networks can be applied to various flow control methods for improving the networking performance. Using SDN controllers, flow routing for moving vehicles can also be performed within a few milliseconds, by simply updating flow rerouting rules at SDN switches whenever needed.

Roadside RRHs: RRHs implement a subset of RSU operations and operate like antenna arrays that establish signal-level connections between VBSs and vehicles, rather than computing units with full functions of BBUs. Of the RRHs in the connectivity range of a vehicle, RRHs for connections are selected by VBSs based on various selection policies.

III. Inter-RRH Mobility Support in vCRAN

A vCRAN can support seamless connectivity session management for moving vehicles. We consider two RRH selection policies, which enable the VBS to change RRHs, in order to maintain session connections to moving vehicles. When a vehicle requests a data service, a VBS instance is created in the MEC server to handle the request. Then, the VBS selects a roadside RRH within connectivity range of the vehicle. As the vehicle travels further from the currently connected RRH and the signal strength weakens, the VBS must select a new RRH, to maintain connectivity with the vehicle and retain a certain QoS for the data service. Because multiple candidate RRHs may be capable of transmitting signals to vehicles, it is necessary to determine an appropriate policy for selecting the RRH or set of RRHs to be used for data service to vehicles. A VBS may simply select RRHs that are capable of providing the strongest signal when the signal strength to the currently connected RRH becomes lower than a threshold. On the other hand, from the candidate RRHs, VBSs may select lightly loaded RRHs instead of heavily loaded ones, in order to achieve load balancing because lightly overloaded RRHs can be exploited to serve more vehicles without degrading the performance of their ongoing services.

Although a VBS newly designates an RRH for establishing a wireless connection with a vehicle moving outside the connectivity range of the currently RRH, the vehicle may not be provided services during this handover process. To support seamless vehicular service, we propose an inter-RRH mobility support using SDN-aided cooperative transmission. For vehicles move outside the connectivity range of the currently connected RRHs, the VBSs at the MEC servers assign other RRHs that newly support the vehicles before the connections between vehicles and currently connected RRHs are disabled. The vehicles at the cell edge of RRHs are connected to multiple RRHs, and the multiple RRHs cooperatively perform downlink/uplink transmissions, as shown in Fig. 2. Consequently, the connections between RRHs and vehicles are maintained even for the vehicles move across

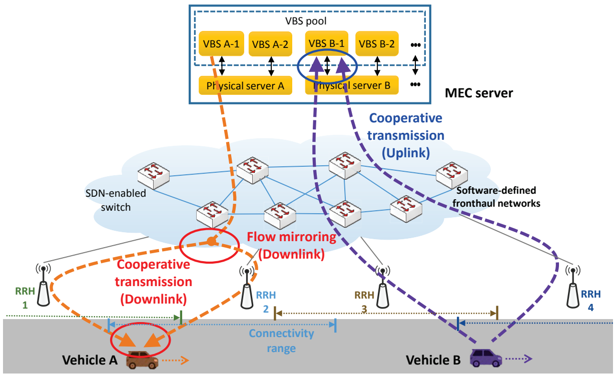


Fig. 2. Inter-RRH mobility support using cooperative transmissions.

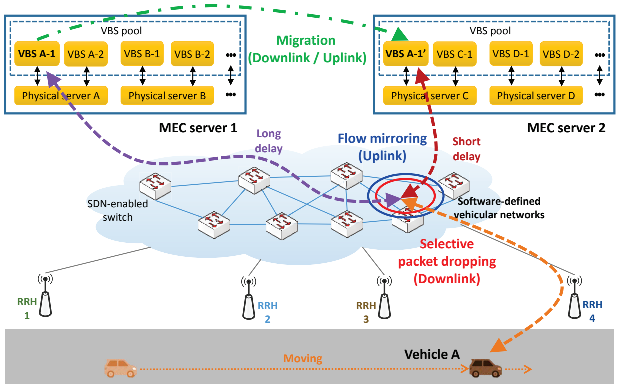


Fig. 3. Inter-MEC-server mobility support with migration.

the cells, and seamless vehicular services can be supported. Note that for cooperative transmissions, a VBS in a MEC server must transmit the same data to multiple RRHs. This process requires a multicast transmission from a VBS to multiple RRHs. Instead of generating multiple flows, the VBS generates a single flow, and the flow can be mirrored (duplicated) at SDN-enabled switches near the destination, so that cooperating RRHs receive the same data. This SDN-based flow mirroring can significantly reduce traffic overheads for cooperative transmissions in vCRAN.

Downlink cooperative transmission for inter-RRH mobility support: To perform a coordinate transmission with SDN support, as shown in Fig. 2, the generated downlink flow is mirrored using an SDN technique at the SDN-enabled switch near the selected RRHs, so that each mirrored flow approaches each selected RRH for coordinated transmission. To efficiently increase SINR at the vehicle using this coordinated transmission technique, downlink signals must be constructively combined at the vehicle using a beam-forming technique [5].

Uplink cooperative transmission for inter-RRH mobility support: As shown in Fig. 2, when a vehicle is far from RRHs, multiple RRHs receive signals, and deliver the received signals to the same VBS. At the VBS, a diversity combining technique is used to combine multiple received signals into a single signal with improved SINR. For a maximal-ratio combining, all of the received signals can be weighted according to their SINR level and summed to a signal with high SINR [6].

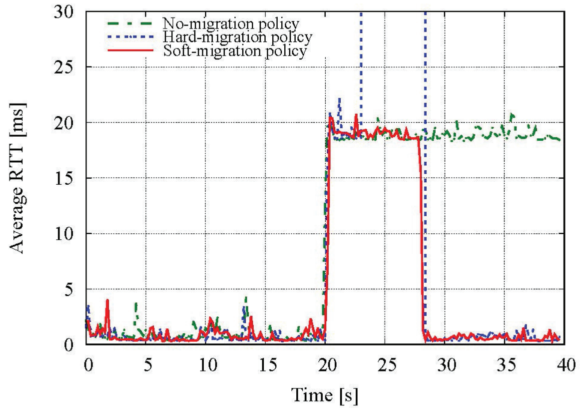
IV. Inter-MEC-Server Mobility Support in vCRAN

A. VBS Management and Migration

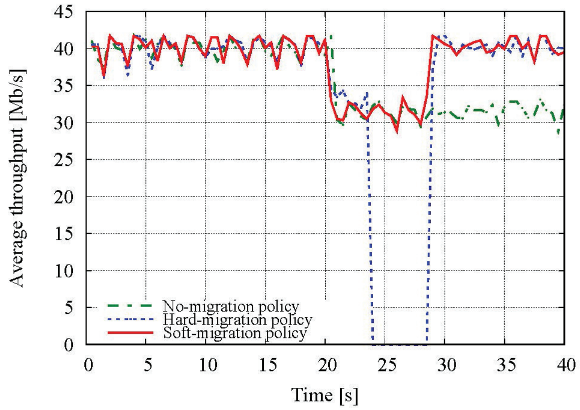
Within a MEC server providing services to a moving vehicle, an individual VBS can be relocated to a different MEC server near the vehicle to reduce delay between the vehicle and MEC server and improve the QoS of the data service. This moving process between MEC servers can be performed using VM migration technology, by which a VBS instance is restored on a MEC server close to the vehicle. To support VBS restoration, information (such as storage, memory, or the central processing unit (CPU) status of the VBS that previously supported the vehicle) must be transferred to the new MEC server that will support the vehicle. In general, when migration is required, the previous VBS is suspended, and the information for VBS migration is transferred [7]. When a MEC server receives the migration information from another MEC server, a VBS instance is restored using the transferred information. After the migration has been completed, the restored VBS can support the vehicle, just as the VBS in the previous MEC server did. For this type of conventional hard-migration approach, however, VBS operations are disabled during migration, and the vehicle is not provided with services during the downtime interval.

Instead, we propose using soft-migration. In the proposed soft-migration, the previous VBS is not suspended, so that vehicles are seamlessly provided with services with no down-time. When the migration begins, the snapshot of previous VBS such as storage, memory, and CPU status is consistently copied to the new MEC server that is designated by the CU to restore the VBS to support the vehicle. When the new MEC server creates a VBS instance using the received snapshot and this VBS begins to support vehicles, the previous one is suspended. Because VBS operations are enabled during migration, the vehicle can be seamlessly provided with services. For example, as shown in Fig. 3, VBS A-1 in MEC server 1 is responsible for providing vehicular services to Vehicle A. When Vehicle A moves far from MEC server 1, a soft-migration from MEC server 1 to MEC server 2 begins. Note that VBS A-1 is not disabled during this soft-migration. For soft-migration, VBS A-1 remains active until it receives a migration completion message from VBS A-1′ in MEC server 2. When the migration is completed and VBS A-1′ in MEC server 2 is supporting Vehicle A, VBS A-1′ notifies VBS A-1 of the migration completion. VBS A-1 is disabled after it receives the migration completion message from VBS A-1′.

Uplink data transmission during soft-migration: When a soft-migration begins as shown in Fig. 3, The SDN-enabled switch connected to the RRH duplicates and transmits uplink packets to both VBS A-1 in MEC server 1 and VBS A-1′ in MEC server 2. When the migration has been completed and VBS A-1′ notifies VBS A-1 of the migration completion, the SDN-enabled switch stops flow mirroring. Before VBS A-



(a) Average RTT



(b) Average throughput

Fig. 4. Results of the emulation using Mininet-Wifi.

1′ is fully enabled to provide services, the packets traveling to VBS A-1′ may be dropped. Hence, the SDN-enabled switch forwards packets to both VBSs through an SDN flow-mirroring technique. By performing soft-migration, the packet drop rate decreases during the VBS migration process, and uplink data services can be performed seamlessly.

Downlink data transmission during soft-migration: During a soft-migration from MEC server 1 to MEC server 2, before VBS A-1 receives the migration completion message and is disabled, duplicate messages from VBS A-1 and VBS A-1′ may be transmitted. To handle these duplicate messages, a VNF for dropping the duplicated messages is enabled, and an SDN-enabled switch connected to the RRH drops duplicate messages from VBS A-1. By using this soft-migration, a fast-moving vehicle can experience seamless services.

B. Emulation for Mobility Support

For the performance evaluation, we use two computers running VBSs using LXC as MEC servers, and use another computer as a network emulator. The emulation was carried out using Mininet-WiFi, which is capable of providing an SDN environment. The network topology consists of eight OpenFlow-enabled switches, where the wired link capacity is 1 Gbps, and four sequentially located RRHs with a 150 m radius coverage. The vehicle moves with 15 m/s, and the vehicle is associated with RRHs through IEEE 802.11g standard-based wireless communication. The bandwidth is 20 MHz, and the channel follows Rayleigh distribution.

Figure 4(a) shows the round trip time (RTT) for packets when a vehicle moves toward RRH 4 from RRH 1. Under the no-migration policy, packet RTTs abruptly increase when the RRH that the vehicle is connected to changes from RRH 1 to RRH 4. In contrast, under the hard- and soft-migration policies, RTTs show the same increases of RTTs, but the RTTs decrease after the VBS migration. However, under the hard-migration policy, it is seen that there exists an interval with large RTTs right after the migration, as shown in the results. It is because packet transmissions between vehicles and MEC servers are suspended. Fig. 4(b) shows throughput performance for the same scenario. As shown in the results, the proposed soft-migration policy has the highest performance among the compared resource management policies.

V. Conclusions

This paper described a new paradigm for vehicular network architecture using cloud-computing infrastructure and resource management for next-generation vehicular networks. We presented an SDN-based vCRAN with MEC and proposed a resource management method that exploits VM migration based on virtualized cloud computing and SDN technologies to support inter-RRH and inter-MEC-server mobility for dynamic vehicular network environments.

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